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A Re-Analysis of Historical Los Alamos Critical Assembly Reaction Rate Measurements

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Introduction

- Benchmark Descriptions
 - Godiva, Jezebel, Flattop-25 & -Pu, Big-10
- Cross Section Processing
- Flux Spectra
- Calculated & Experimental Results
 - Using ENDF/B-VII.1 & IRDFF-v1.03
- Final Observations

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GODIVA

- HEU-MET-FAST-001.
- ~94 w/o ^{235}U .
- Benchmark model is a simple, one material, sphere.
- Foil activation and fission chamber measurements made near the core center.

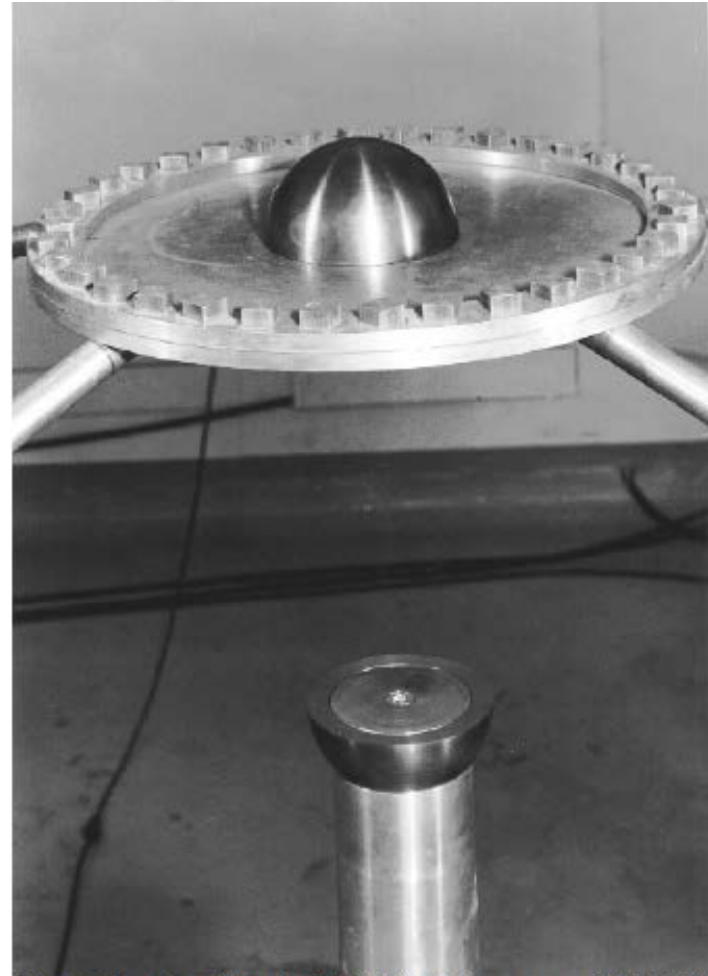


Figure 1. Experimental Setup for the Multiplication Measurements of Spherical Shell Configurations.

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FLATTOP-25

- HEU-MET-FAST-028.
- Spherical HEU “core”.
- Spherical ^{nat}U reflector.
- Foil activation and fission chamber measurements made near the core center and for a radial traverse extending into the reflector.



Figure 5. The Flattop Assembly.

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JEZEBEL

- Pu-MET-FAST-001.
 - Revision 3 added to the ICSBEP Handbook in 2013.
 - Benchmark model used here is a simple, one material, sphere.
 - Foil activation and fission chamber measurements made near the core center.
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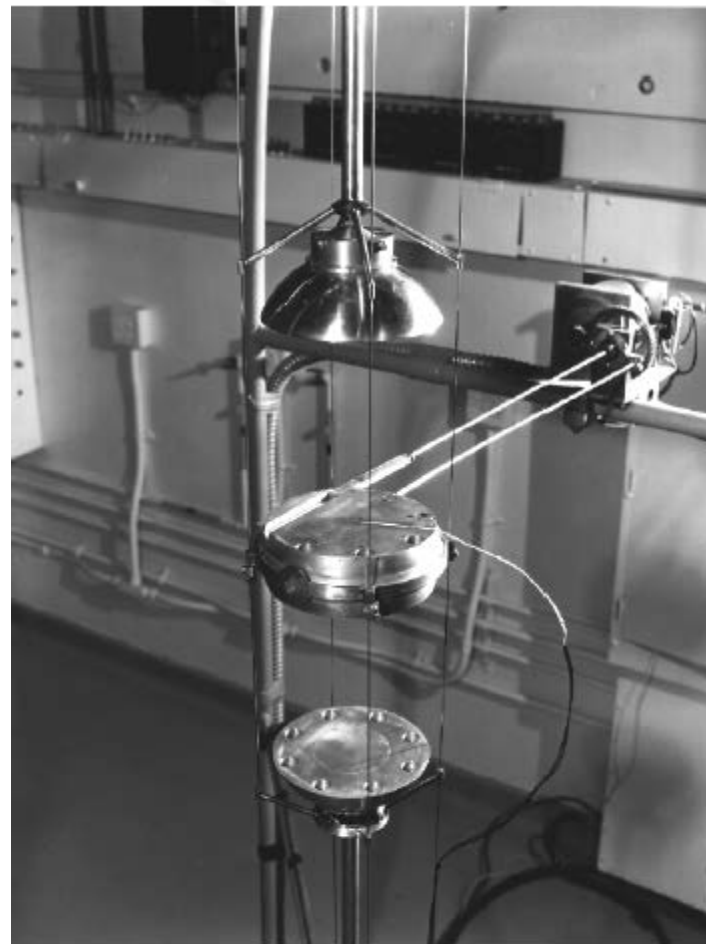


Figure 1. Jezebel in the "Safe" Configuration.*

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FLATTOP-Pu

- Pu-MET-FAST-006
- Spherical Pu “core”.
- Spherical ^{nat}U reflector.
- Foil activation and fission chamber measurements made near the core center.



Figure 5. The Flattop Assembly.

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Big-10

- IMF-MET-FAST-007.
 - A large, heterogeneous uranium critical assembly.
 - Benchmark model used here is a detailed plate-by-plate cylinder.
 - Foil activation and fission chamber measurements made near the core center.
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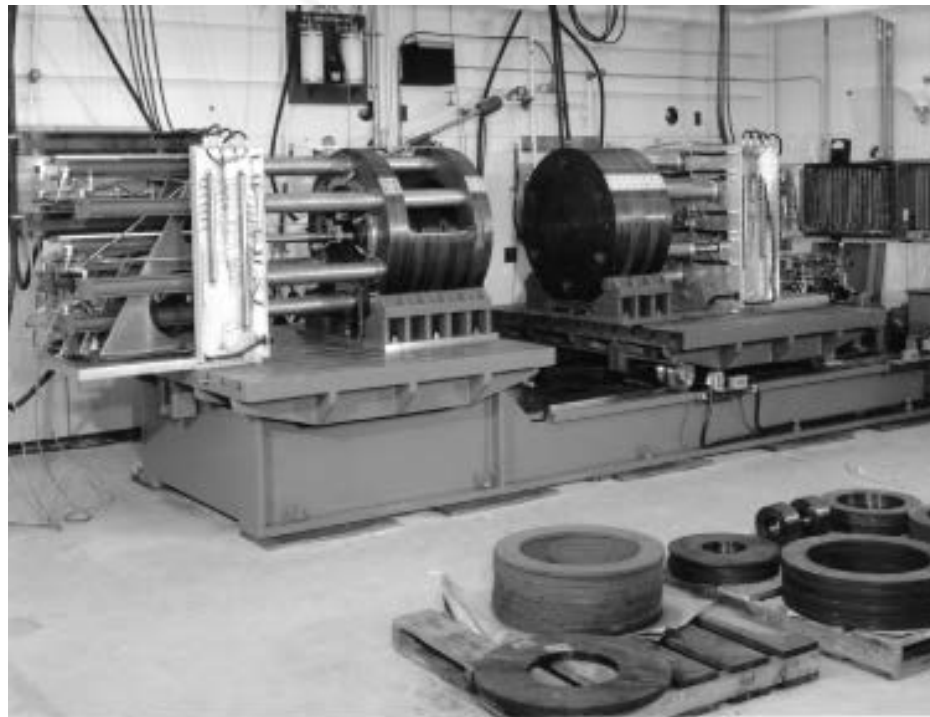


Figure 1. The Big Ten Assembly during Construction (1968).

Measurement Summary - I

- LANL critical assembly reaction rate measurements were made during the 1950s to 1970s
 - Until recently much of this data could only be found in internal LANL memoranda
 - Now becoming available in peer-reviewed literature
 - ENDF/B-VII.0 & VII.1 NDS 2006 & 2011 “Big Papers”;
 - P.G.Young *et al*, NDS **108**, 2589(2007);
 - ND2013 Proceedings (Chadwick *et al*).

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Measurement Summary - II

- LANL critical assembly reaction rate measurements were made during the 1950s to 1970s
 - Reported results depend upon the “known” 14.1 MeV cross section at that time.

Reaction	Pre-1963	Post-1963	ENDF/B-7.1
$^{45}\text{Sc}(n,2n)^{44\text{m}}\text{Sc}$	0.115	0.105	0.104
$^{51}\text{V}(n,a)^{48}\text{Sc}$	0.0157		0.0152
$^{75}\text{As}(n,2n)^{74}\text{As}$	1.050		0.994
$^{89}\text{Y}(n,2n)^{88}\text{Y}$	0.670	0.845	0.850
$^{90}\text{Zr}(n,2n)^{89}\text{Zr}$	0.643	0.590	0.617
$^{103}\text{Rh}(n,2n)^{102\text{m}}\text{Rh}$	0.750	0.783	0.741
$^{107}\text{Ag}(n,2n)^{106\text{m}}\text{Ag}$		0.573	0.520
$^{169}\text{Tm}(n,2n)^{168}\text{Tm}$		1.96	1.980
$^{175}\text{Lu}(n,2n)^{174}\text{Lu}$		1.789	2.122
$^{191}\text{Ir}(n,2n)^{190\text{x}}\text{Ir}$		1.995	2.066
$^{197}\text{Au}(n,2n)^{196}\text{Au}$		2.214	2.132
$^{203}\text{Tl}(n,2n)^{202}\text{Tl}$	1.428	2.090	2.005
$^{204}\text{Pb}(n,2n)^{203}\text{Pb}$	1.746		2.193
$^{238}\text{U}(n,2n)^{237}\text{U}$		0.895	0.850

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Cross Section Processing

- ENDF/B-VII.1 results use the .80c cross sections distributed with MCNP6.1
- IRDFF-v1.03 results use MCNP “dosimetry” class (.##y) files processed at LANL with NJOY.
 - IRDFF files are in a pointwise format and already Doppler broadened to 300K
 - Only need to run NJOY’s “ACER” module
 - Linearization is NOT necessary

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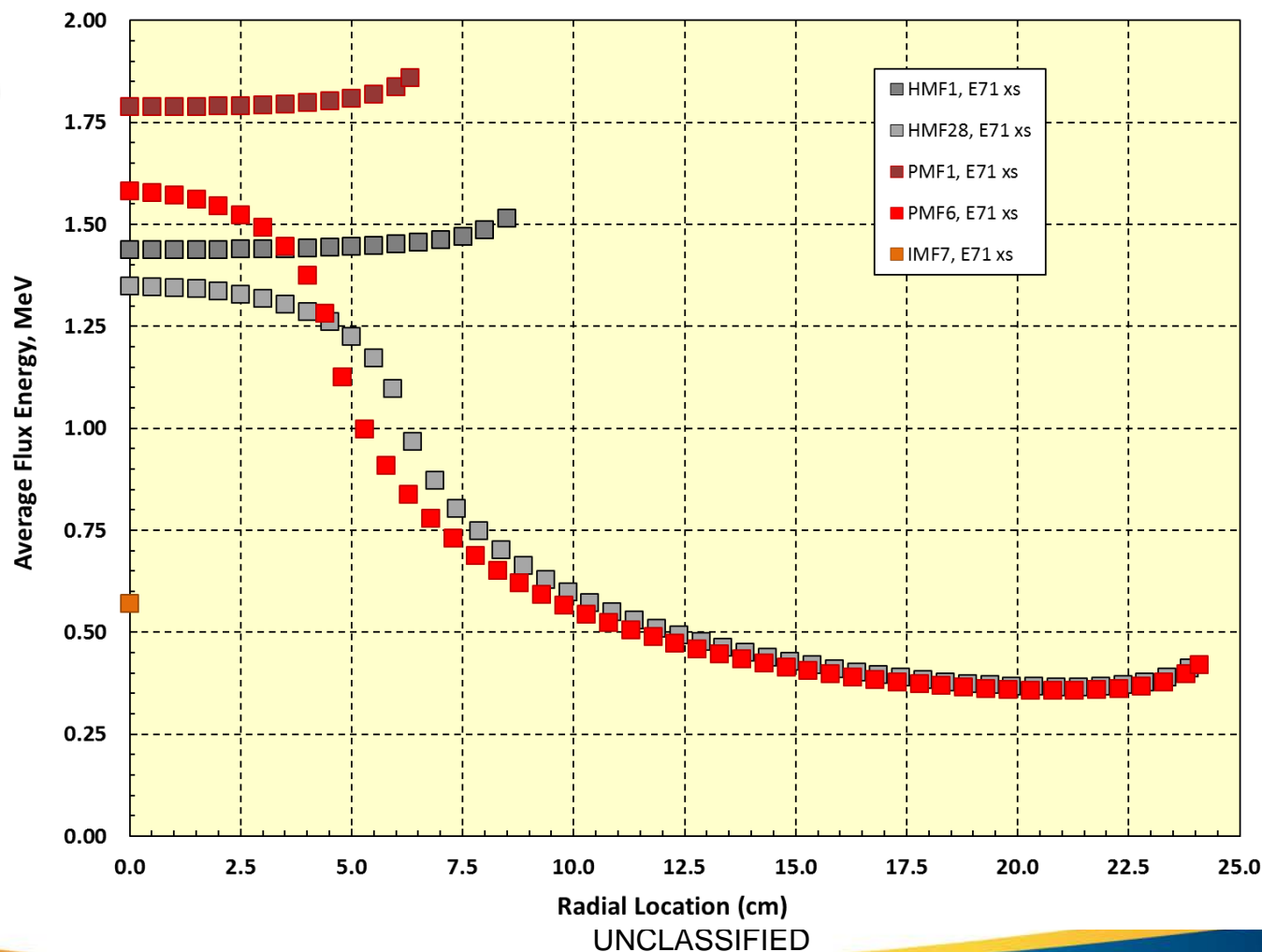
MCNP6 Calculation Strategy

- Run 10 independent 500M neutron history jobs
 - 100,000 histories per cycle, 5,000 cycles plus 25 “warm-up cycles.
- Define tally regions for
 - 0.5 cm diameter central sphere;
 - 0.5 cm thick shells with increasing radius.
- Save “mctal” file for each job.
- Use the supplied “merge_mctal.pl” utility to combine the 10 mctal files.

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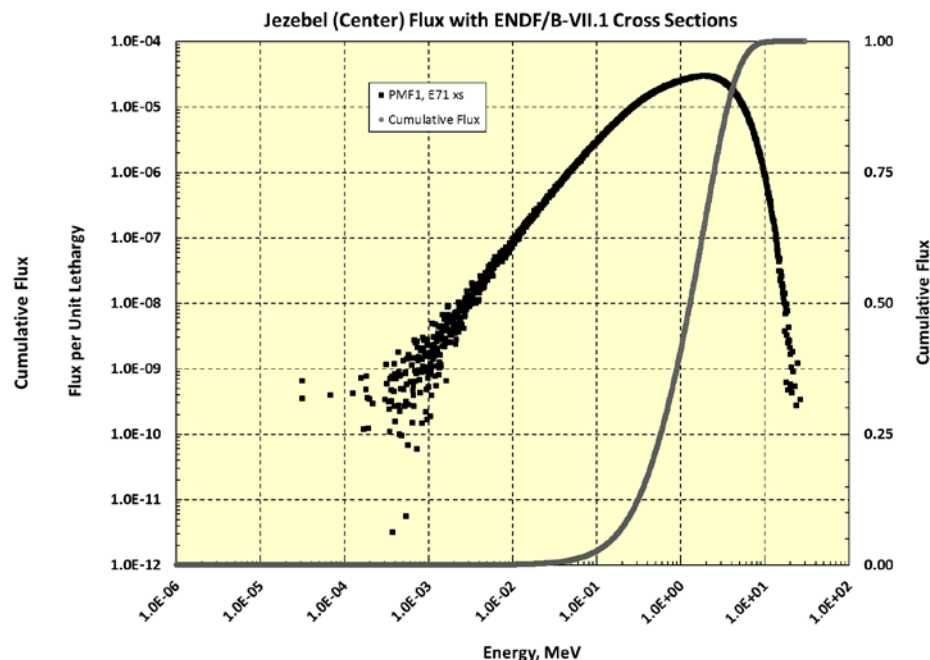
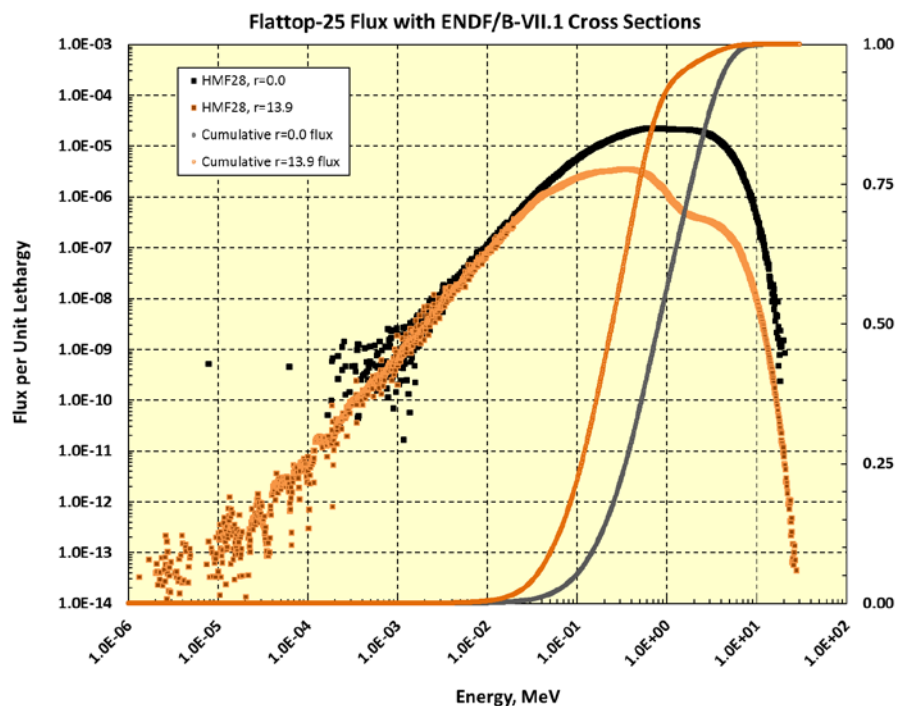
Critical Assembly Average Flux Energy - I

Average Flux Energy for Various LANL FAST Critical Assemblies



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Critical Assembly Average Flux Energy - II

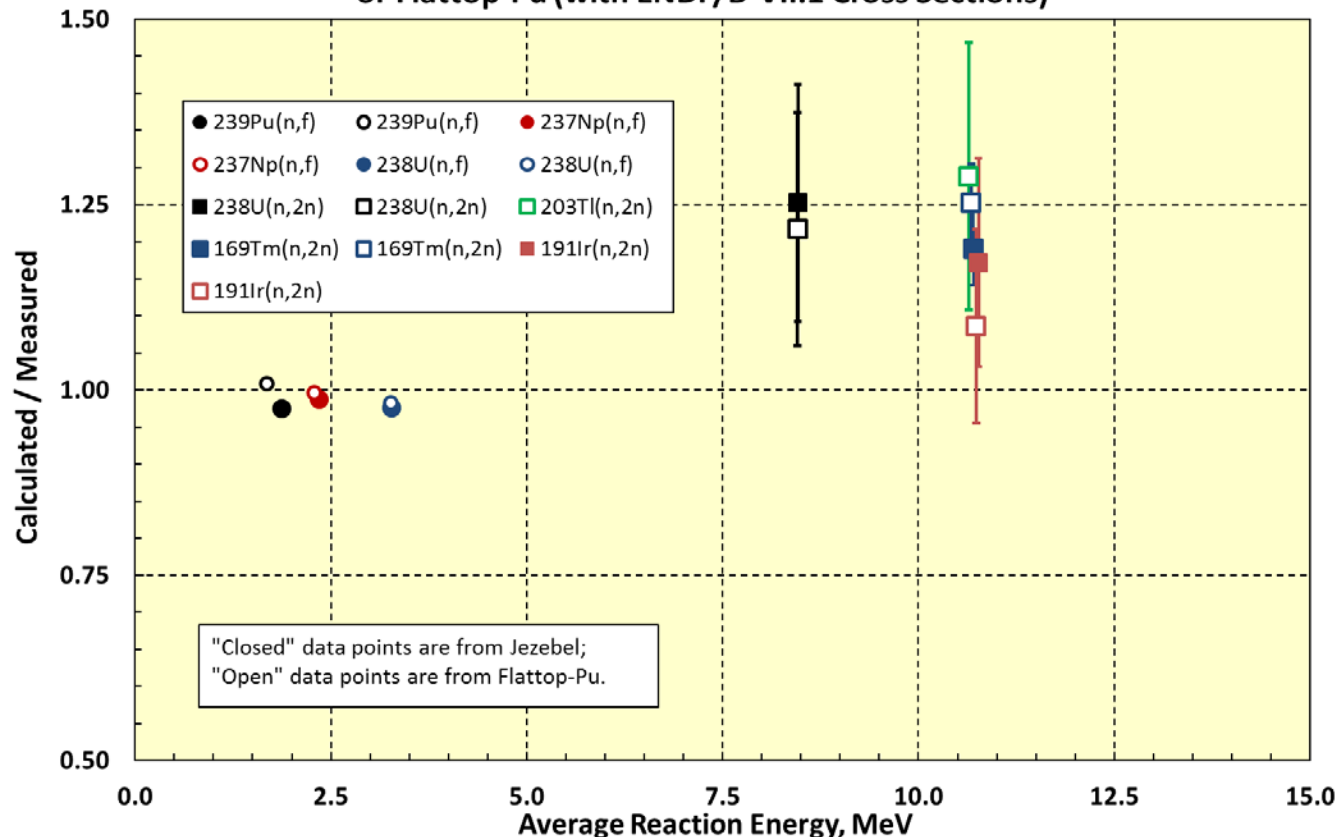


Critical assembly flux distributions are nowhere near mono-energetic; rather they span hundreds of keV/MeV.

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Jezebel & Flattop-Pu Results

Selected Spectral Index Data for the Central Region of Jezebel
or Flattop-Pu (with ENDF/B-VII.1 Cross Sections)



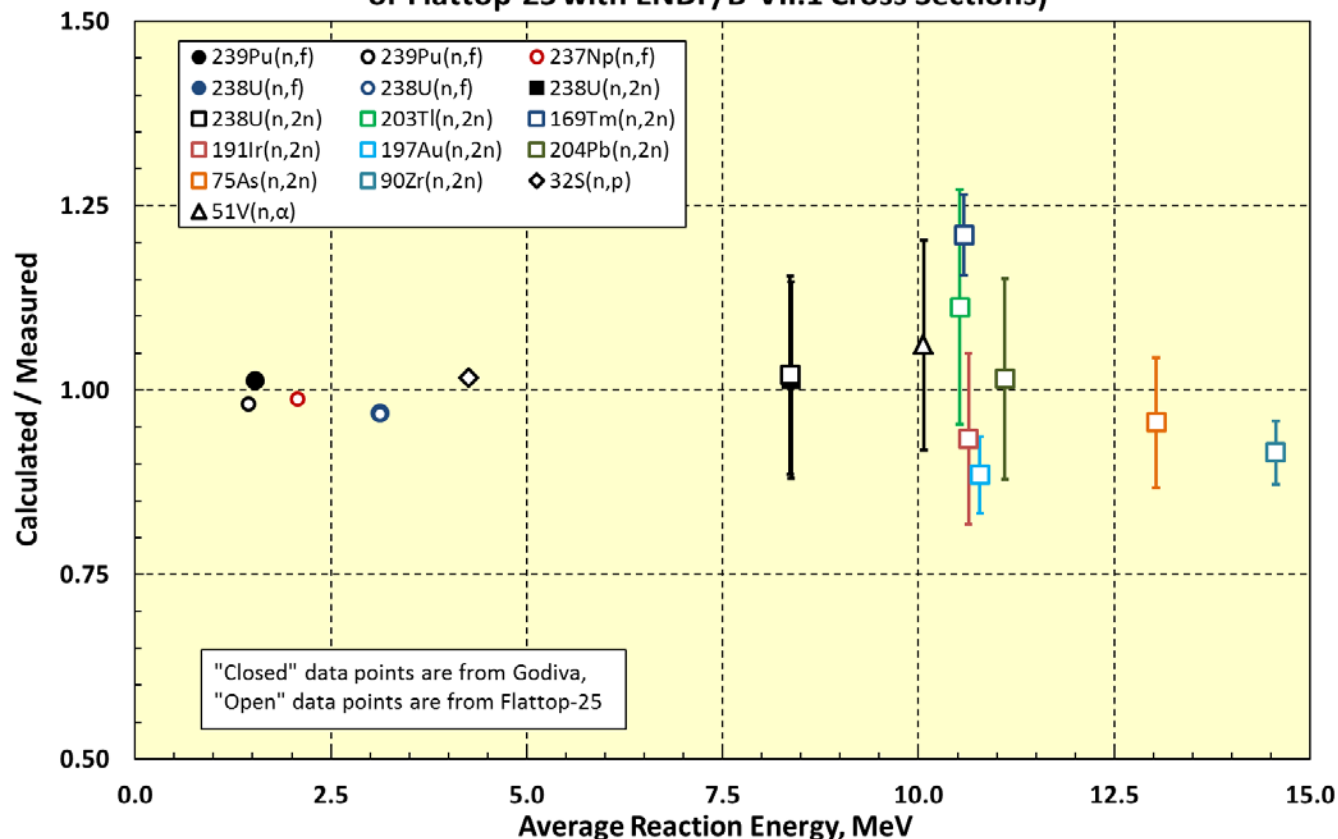
Near unity C/E results are seen at low energies for ^{238}U , ^{237}Np & ^{239}Pu (n,f) spectral indices.

C/E's seem biased high at larger average reaction rate energies ... but pfn's uncertainties are not included.

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Godiva & Flattop-25 Results

Selected Spectral Index Data for the Central Region of Godiva
or Flattop-25 with ENDF/B-VII.1 Cross Sections)



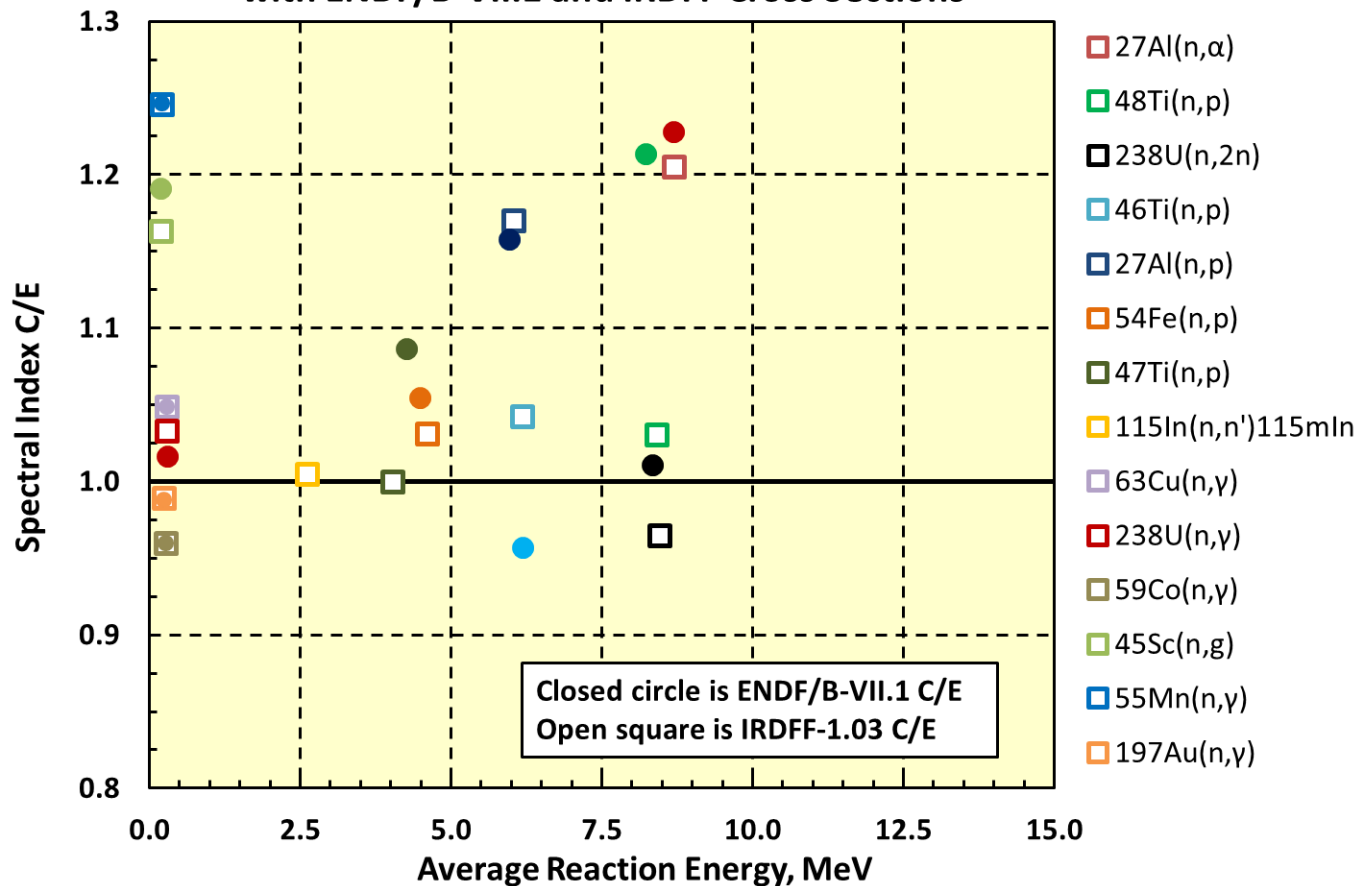
Near unity C/E results are seen at low energies for ^{238}U , ^{237}Np & ^{239}Pu (n,f) and $^{32}\text{S}(n,p)$ spectral indices.

In contrast to Pu fuelled critical assemblies, these C/E 's remain near unity throughout the measured energy range.

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Big-10 Results

Spectral Index C/E Values for Big-10 with ENDF/B-VII.1 and IRDFF Cross Sections



E71=open square.

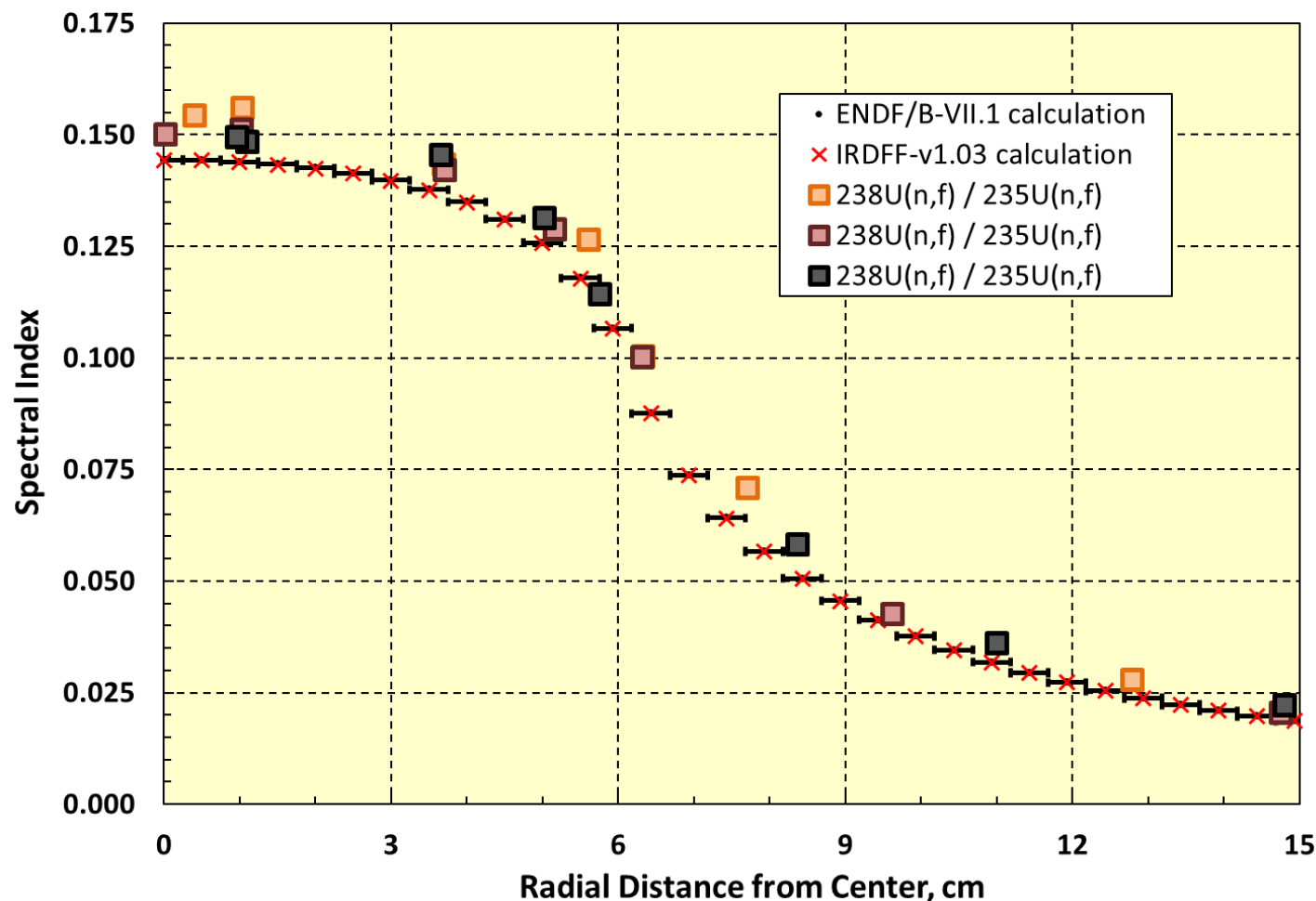
IRDFF-v1.03=closed circle.

Capture reactions, such as $^{45}\text{Sc}(n,\gamma)$ and $^{55}\text{Mn}(n,\gamma)$ need further review.

*Large differences
between ENDF and
IRDFF need further
review ... ^{45}Sc ,
 $^{46,48}\text{Tl}$.*

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$^{238}\text{U}(n,f)$ Spectral Index in Flattop-25



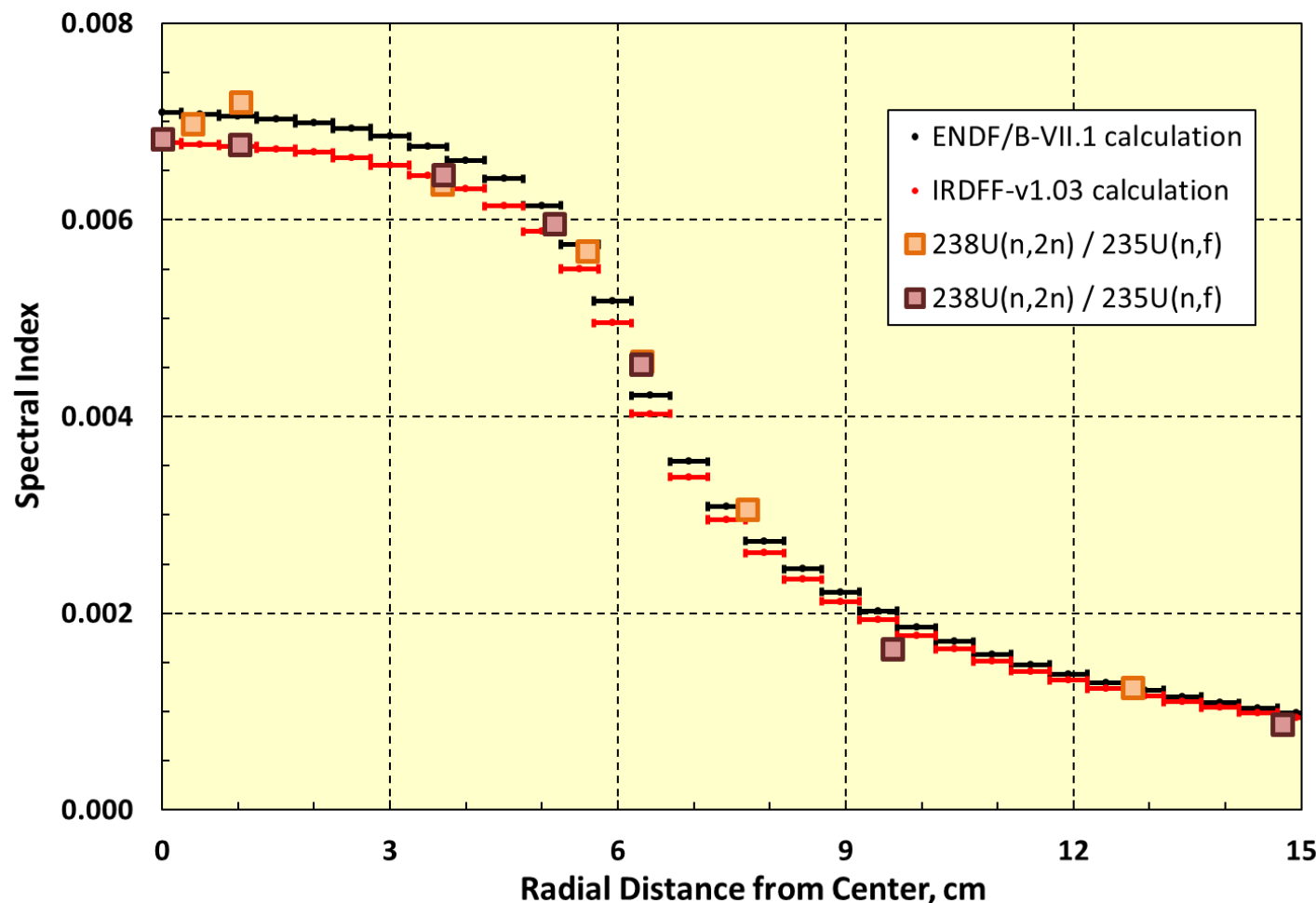
$^{238}\text{U}(n,f)$
spectral index
versus radius
in Flattop-25.

Horizontal
“error bars”
denote radial
shell tally (with
ENDF/B).

“×” is IRDFF-
v1.03 .

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$^{238}\text{U}(n,2n)$ Spectral Index in Flatop-25



$^{238}\text{U}(n,2n)$ spectral index versus radius in Flatop-25.

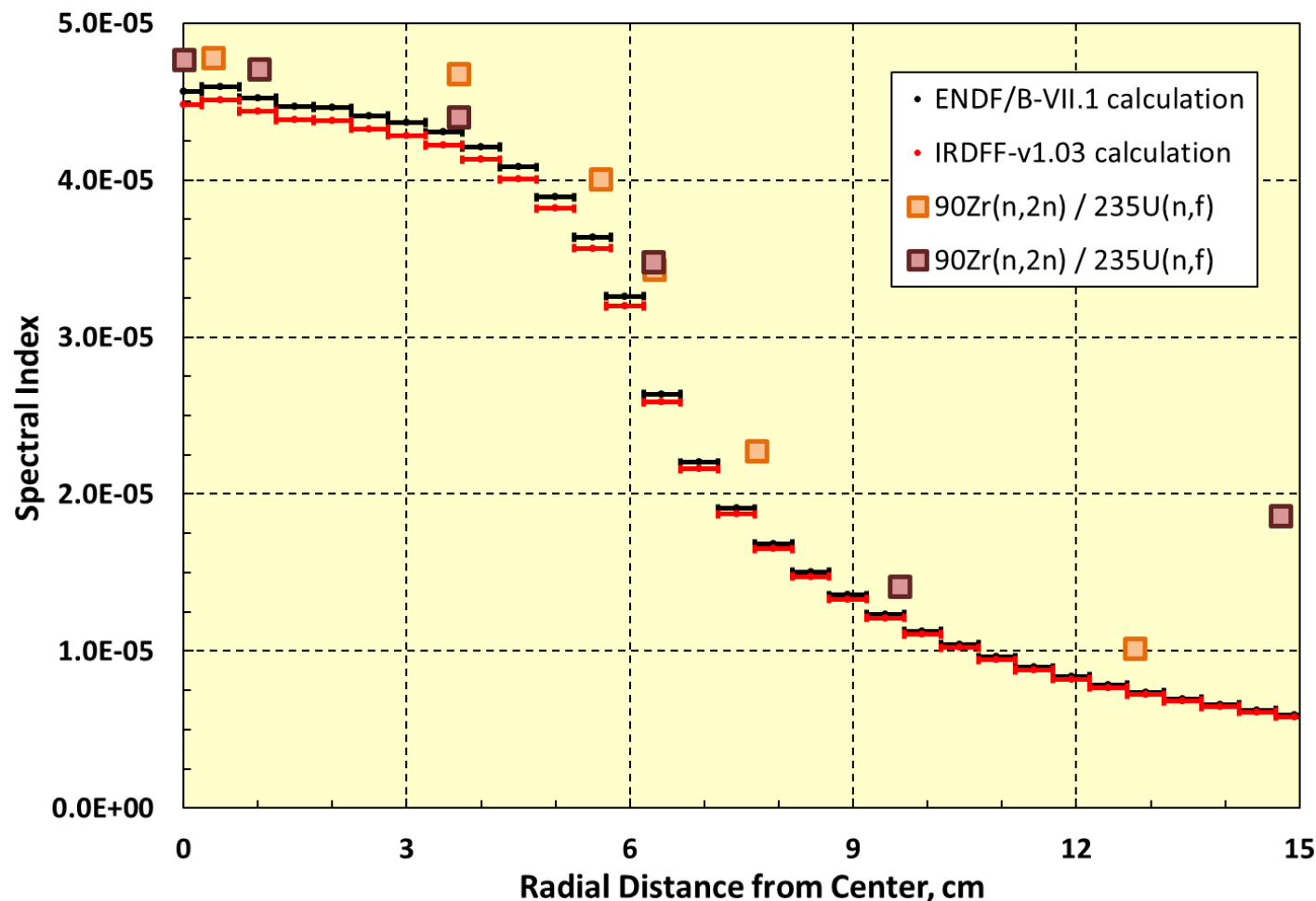
Horizontal “error bars” denote radial shell tally (with ENDF/B).

“X” is IRDFF-v1.03.

There is a clear difference between ENDF and IRDFF

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$^{90}\text{Zr}(n,2n)$ Spectral Index in Flattop-25



One of the highest average energy reactions ... there is a clear $C/E < 1$ bias for all radii.

Outermost radial measurement seems anomalous.

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Final Observations

- Not conclusions, as the story is clearly not complete ...
 - pfns studies remain a work in progress
 - An IAEA CRP on this topic has yet to reach a consensus.
 - New measurements and advanced fission theory work continues at LANL.
 - Differences among major cross section libraries remains an unresolved issue (but we're working on it ... e.g. the WPEC "CIELO" Project).

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